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DATA PAPER

Early geomagnetic data from the Astronomical Observatory of Madrid (1879–1901)

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Abstract

The recovery of early geomagnetic data is essential to improve knowledge of the evolution of the geomagnetic field. A recently recovered dataset is described that includes mean decadal (10 days) values of the geomagnetic declination and some disperse values of geomagnetic inclination measured at the Astronomical Observatory of Madrid from 1879 to 1901. These recovered data are compared directly with the results obtained from a geomagnetic model. The data have now been made accessible for the scientific community in digital form.

1 | INTRODUCTION

Geomagnetic data recorded in the past have undoubted interest for long-term studies of the evolution of the geomagnetic field, especially over the last five centuries (Jonkers, 2003). In the 19th century, a network of geomagnetic observatories covered Europe and extended to many places on the Earth. Thus, for example, we today have long-term geomagnetic records of some European cities including London (Malin and Bullard, 1981; Barraclough *et al.*, 2000) and Paris (Alexandrescu *et al.*, 1996), as well as records of the great geomagnetic storms that occurred more than 100 years ago (Tsurutani, 2003; Vaquero *et al.*, 2008; Ribeiro *et al.*, 2011, 2016). Although a considerable amount of geomagnetic data from the last four centuries are available thanks to measurements made on ships (Jonkers, 2003), the initiation of systematic measurements at geomagnetic observatories occurred in the 19th century (Cawood, 1979). In particular, we can mention the "magnetic crusade" of Sabine and the "magnetic union" of Gauss. In the Iberian Peninsula, several geomagnetic observatories were found in the second half of the 19th century including Madrid, Lisbon, Coimbra, San Fernando, and Casa Balaguer (Cubillo, 1949; González, 1992; Pais and Miranda, 1995; Batlló, 2005; Morozova *et al.*, 2014; Ribeiro *et al.*, 2016). Note that the unique observatory in Spain with continuous geomagnetic record is San Fernando, in the South coast. Regular observations started around 1879, but publication started just in 1891. This situation gives its proper value to the recovery of early geomagnetic observations from other places in Spain.

Dataset
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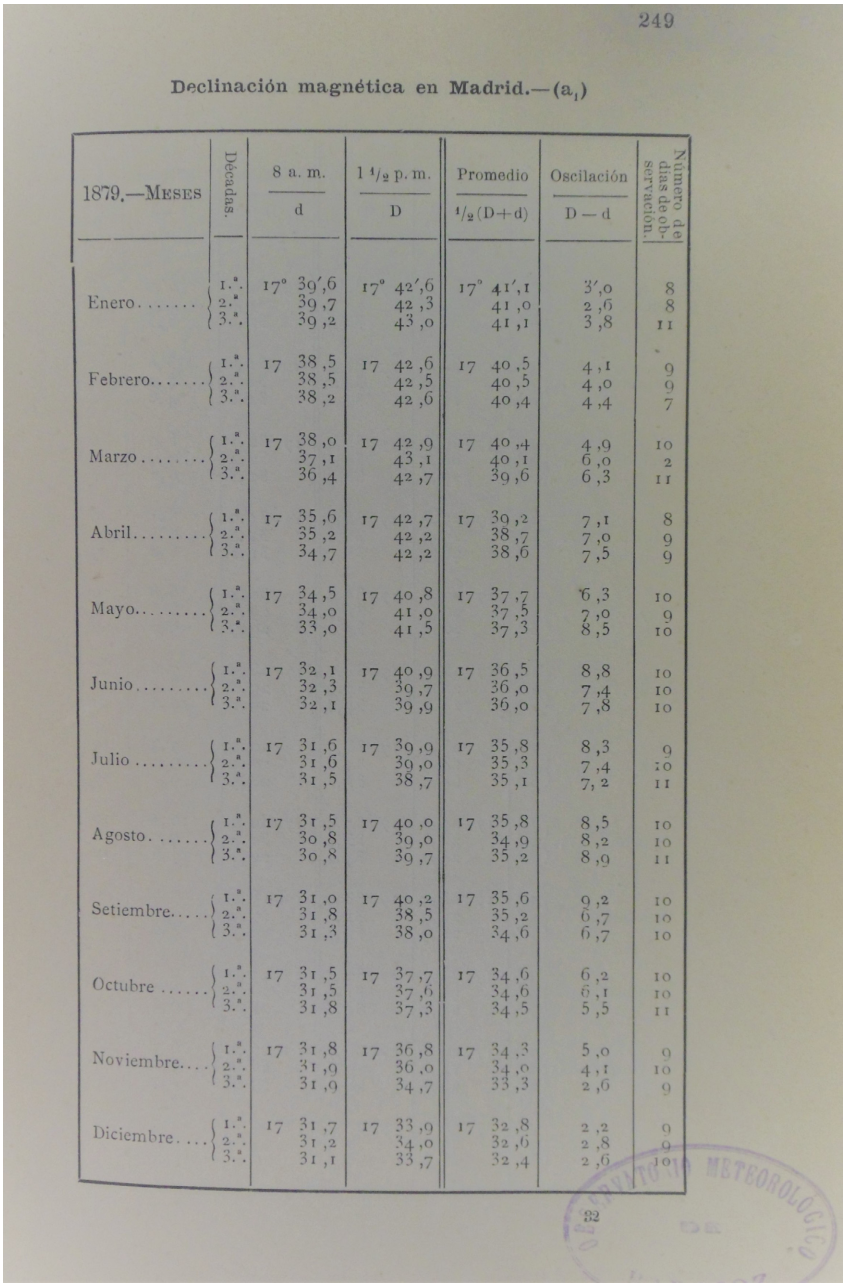
The aim of this article was to provide the scientific community with a set of geomagnetic data in digital format that were originally published in the historical yearly books of the Astronomical Observatory of Madrid spanning the period from 1879 to 1901. The list of bibliographic references used to compile the data is presented in a Bibliographic appendix. Although the Observatory was found in the 18th century (López Arroyo, 2004), the period of maximum activity of this institution was the second half of the 19th century and the first third of the 20th century. This institution was not only responsible for astronomical work but also coordinated national efforts in the Earth physics, especially in meteorology (Anduaga Egaña, 2012).

2 | DATA AND INSTRUMENTS

The recovered data are mainly observations of magnetic declination from the Observatory of Madrid (Spain) for the time interval 1879–1901. The observations were made every day at 8 hr and 13 hr 30 min (Local Time), the approximate times for the minimum and maximum declinations in a day at this observatory. Unfortunately, these daily observations have disappeared, and only the mean values for every decade of days were published. The use of decades was very usual in the late 19th century, especially in meteorology. The days of the month were grouped into the first (from 1 to 10), the second (from 11 to 20), and



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Declinación magnética en Madrid.—(a₁)

1879.—MESES	Décadas.	8 a. m. d	1 ½ p. m. D	Promedio ½(D+d)	Oscilación D — d	Número de días de observación.
Enero	1.ª	17° 39′,6	17° 42′,6	17° 41′,1	3′,0	8
	2.ª	39 ,7	42 ,3	41 ,0	2 ,6	8
	3.ª	39 ,2	43 ,0	41 ,1	3 ,8	11
Febrero	1.ª	17 38 ,5	17 42 ,6	17 40 ,5	4 ,1	9
	2.ª	38 ,5	42 ,5	40 ,5	4 ,0	9
	3.ª	38 ,2	42 ,6	40 ,4	4 ,4	7
Marzo	1.ª	17 38 ,0	17 42 ,9	17 40 ,4	4 ,9	10
	2.ª	37 ,1	43 ,1	40 ,1	6 ,0	2
	3.ª	36 ,4	42 ,7	39 ,6	6 ,3	11
Abril	1.ª	17 35 ,6	17 42 ,7	17 39 ,2	7 ,1	8
	2.ª	35 ,2	42 ,2	38 ,7	7 ,0	9
	3.ª	34 ,7	42 ,2	38 ,6	7 ,5	9
Mayo	1.ª	17 34 ,5	17 40 ,8	17 37 ,7	6 ,3	10
	2.ª	34 ,0	41 ,0	37 ,5	7 ,0	9
	3.ª	33 ,0	41 ,5	37 ,3	8 ,5	10
Junio	1.ª	17 32 ,1	17 40 ,9	17 36 ,5	8 ,8	10
	2.ª	32 ,3	39 ,7	36 ,0	7 ,4	10
	3.ª	32 ,1	39 ,9	36 ,0	7 ,8	10
Julio	1.ª	17 31 ,6	17 39 ,9	17 35 ,8	8 ,3	9
	2.ª	31 ,6	39 ,0	35 ,3	7 ,4	10
	3.ª	31 ,5	38 ,7	35 ,1	7, 2	11
Agosto	1.ª	17 31 ,5	17 40 ,0	17 35 ,8	8 ,5	10
	2.ª	30 ,8	39 ,0	34 ,9	8 ,2	10
	3.ª	30 ,8	39 ,7	35 ,2	8 ,9	11
Setiembre	1.ª	17 31 ,0	17 40 ,2	17 35 ,6	9 ,2	10
	2.ª	31 ,8	38 ,5	35 ,2	6 ,7	10
	3.ª	31 ,3	38 ,0	34 ,6	6 ,7	10
Octubre	1.ª	17 31 ,5	17 37 ,7	17 34 ,6	6 ,2	10
	2.ª	31 ,5	37 ,6	34 ,6	6 ,1	10
	3.ª	31 ,8	37 ,3	34 ,5	5 ,5	11
Noviembre	1.ª	17 31 ,8	17 36 ,8	17 34 ,3	5 ,0	9
	2.ª	31 ,9	36 ,0	34 ,0	4 ,1	10
	3.ª	31 ,9	34 ,7	33 ,3	2 ,6	9
Diciembre	1.ª	17 31 ,7	17 33 ,9	17 32 ,8	2 ,2	9
	2.ª	31 ,2	34 ,0	32 ,6	2 ,8	9
	3.ª	31 ,1	33 ,7	32 ,4	2 ,6	10

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FIGURE 1 Example of magnetic declination data published by the Observatory of Madrid for 1879: month, 10-day group (decade), mean value for 10 days at 8 hr, mean value for 10 days at 13 hr 30 min, mean value and difference between these last two values, and number of days with observations

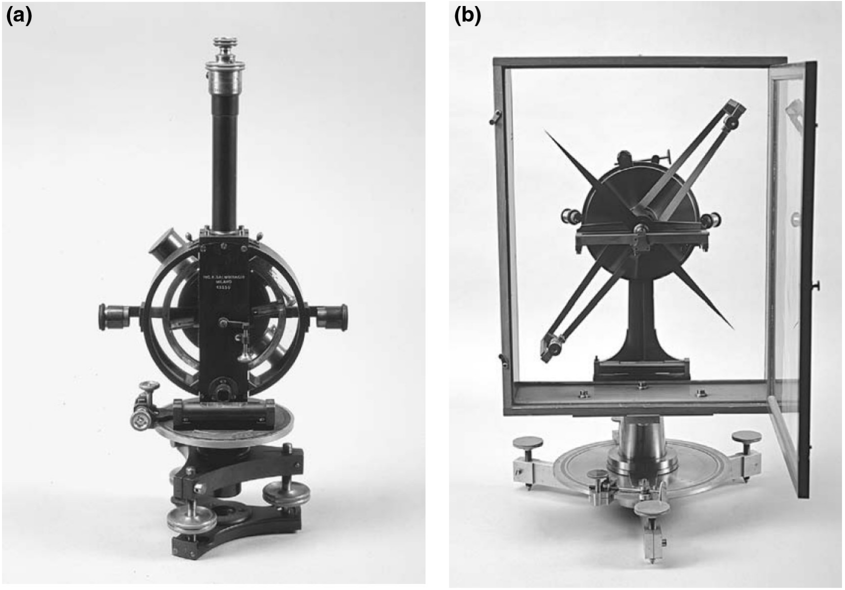

FIGURE 2 (a) Brunner magnetic theodolite and (b) Brunner inclinometer (Batlló, 2005)

the third decades (from 21 to 28 or 29 or 30 or 31, depending on the month).

In particular, we have used several volumes corresponding to biannual publications of meteorological data of the Observatory of Madrid for the period 1879–1901. The publications comprise several types of tables. Firstly, the calculated mean decadal values corresponding to 8 hr (*d*) and to 13 hr 30 min (*D*), the average of these two observations $(d + D)/2$, their differences (*D*-*d*), and the number of days with observations (Figure 1) are shown for each year. The next tables in the publications list the monthly mean values for each year, and finally there are several tables that summarize the previous ones.

We have some information about the instrument. The observations were made with a Brunner magnetic theodolite that the Observatory acquired in 1878 (Figure 2a). The accuracy is approximately 1’, thanks to the observer's good work. However, as one sees in Figure 1, the data were noted down to a tenth of a minute because they were decadal means. Batlló (2005) explain that there are problems in the identification of this instrument due to the discordance between the dates noted in the publications and those of the inventories of instruments. However, Batlló (2005) states that the used magnetic theodolite could be the one shown in Figure 2a.

Magnetic inclination observations are also reported in the publications, but only for a few days of the years 1878, 1879, 1881, and 1892 (Table 1). Afterwards, these observations were interrupted due to a fault in the instrument, an inclinometer built by Brunner (Paris) (Figure 2b), in particular, in the magnetic needle. In 1900, some observations were again made, but they were discontinued after that because of the disturbances caused by electrical tram lines in the city.

We have digitized all the magnetic data available in the cited publications. A basic quality control was done, finding that, in particular, the difference between one decadal value of geomagnetic declination and the next was always less than 0.075 degrees (4.5 min).

We carried out a more detailed analysis only with the magnetic declination data because of a greater number and continuous distribution of those observations. Firstly, we calculated the monthly means of the observations taken at 8 hr ($\overline{d}$) and at 13 hr 30 min ($\overline{D}$):

$$\bar{d},\bar{D} = \frac{1}{N}\sum_{i=1}^{3} n_i m_i$$

where N is the total number of observations taken during the month, n_i the number of observations corresponding to decade i, and m_i the mean declination for that group. The Observatory published the mean values calculated without considering any weighting, but the results are very similar, with differences less than a tenth of minute.

We then calculated the mean value for each year as the mean of the monthly means. Figure 3a shows these mean declination values for the two different times (*d* and *D*), and the average value $(d + D)/2$. With these values, we calculated the yearly variation for the declination by a least-squares fit (correlation coefficient equal to 0.99), obtaining an increment of 5.3’/year (Figure 3b). The current secular variation value at Madrid is about 7.5’/year (IGN, 2005).

Detailed secular variation curves from historical data are now available for Europe. For instance, Malin and Bullard (1981) analysed a 400-year series of declination and inclination at London, which was later complemented by Barraclough *et al*. (2000). Archaeomagnetic results for older periods were presented by Gallet *et al*. (2002) from burnt

TABLE 1 Magnetic inclination data. For each date, the values of the observed and modelled (using *gufm1*) data are shown. Moreover, the differences between these values are also shown

Year	Month	Day	Observed geomagnetic inclination (° ´)	Calculated geomagnetic inclination (° ´)	Observed – calculated (´)
1878	9	4	59 42.2	59 43.8	−1.6
1878	9	14	59 40.2	59 43.8	−3.6
1878	9	28	59 41.5	59 43.2	−1.7
1878	10	5	59 41.0	59 43.2	−2.2
1878	10	26	59 41.1	59 43.2	−2.1
1878	10	30	59 39.7	59 43.2	−3.5
1878	11	8	59 41.3	59 43.2	−1.9
1878	11	16	59 42.5	59 43.2	−0.7
1878	11	30	59 39.6	59 42.6	−3.0
1878	12	5	59 41.3	59 42.6	−1.3
1878	12	7	59 42.0	59 42.6	−0.6
1878	12	27	59 40.2	59 42.6	−2.4
1879	1	31	59 40.5	59 42.0	−1.5
1879	3	1	59 39.0	59 42.0	−3.0
1879	3	26	59 37.2	59 42.0	−4.8
1879	12	22	59 36.9	59 39.6	−2.7
1881	11	3	59 36.0	59 34.2	1.8
1881	11	6	59 34.0	59 34.2	−0.2
1881	11	7	59 35.1	59 34.2	0.9
1881	11	25	59 36.0	59 34.2	1.8
1892	5	21	59 08.3	59 09.0	−0.7
1892	5	23	59 08.3	59 09.0	−0.7
1892	5	23	59 08.2	59 09.0	−0.8
1900	1	4	58 34.5	58 44.4	−9.9
1900	2	7	58 42.1	58 43.8	−1.7
1900	2	9	58 44.2	58 43.8	0.4
1900	2	12	58 48.0	58 43.8	4.2
1900	3	5	58 41.0	58 43.8	−2.8
1900	7	17	58 35.1	58 42.6	−7.5
1900	9	15	58 34.0	58 42.0	−8.0
1900	10	4	58 34.3	58 41.4	−7.1
1900	10	26	58 38.2	58 41.4	−3.2
1900	12	1	58 29.3	58 41.4	−12.1

archaeological structures found at two French sites dated within the first millennium B.C. For Spain, Gómez-Paccard *et al.* (2006) obtained the secular variation curve for the Iberian Peninsula using 134 archaeomagnetic directions with ages ranging from −775 to 1959 A.D. Although the series of the present work is much shorter, there is general agreement between the two. For instance, for 1882, the observed D mean value in Madrid is −17.4° and the obtained by Gómez-Paccard *et al.* (2006) is −17.2°.

It is interesting to note that three determinations of the horizontal component H made at the Madrid Observatory using the Gauss method (and units) are mentioned in the Observatorio de Madrid (1904d). The first measurement was made by Lamont in June 1857 (H = 0.21718). The second measurement was made by the Jesuit Father Martín Juan (from Observatorio de Manila) on November 12, 1886 (H = 0.22676). The last mentioned measurement was made by the Observatory staff on May 25, 1901 (H = 0.22821).

3 | COMPARISON WITH GEOMAGNETIC MODELS

We compared our calculated annual mean observations with those obtained by a theoretical model. In particular, we used the *gufm1* model (Jackson *et al*., 2000) which is based on a compilation of historical observations of the magnetic field, mainly taken by mariners engaged in merchant and naval shipping. With this model, we calculated the declination value for each day, and then obtained the mean value for each year. Figure 4 shows the yearly mean values as observed and calculated with the *gufm1* model. One notes that the difference between the two series decreases continuously from 1879 to 1897, with a less consistent behaviour after that time. In order to analyse in greater detail this behaviour, the difference between the theoretical values and the observed ones is represented in Figure 5. The greatest difference is 13.2’ corresponding to 1879, and the smallest is 3.0’ in 1899. One also notes a change in the overall trend from 1890 onwards. Indeed, one notes three different time intervals: 1879–1890, 1890–1897, and 1897–1901.

Table 1 shows the observed magnetic inclination values, modelled estimates given by *gufm1*, and the differences between these two sets of values. These differences are between –5´ and 1.8´, except for the value observed on 1 December 1900 which is extraordinarily high (–12.1′). This discrepancy is explained by the magnetic noise coming from the city's infrastructure (López Arroyo, 2004).

4 | CONCLUSIONS

We have here described our recovery of the decadal (10 days) long geomagnetic data from the Observatory of Madrid corresponding to the period 1879–1901 which were published in the annual meteorological books of that institution. In comparing these data with the *gufm1* geomagnetic model, we found their results to be coherent

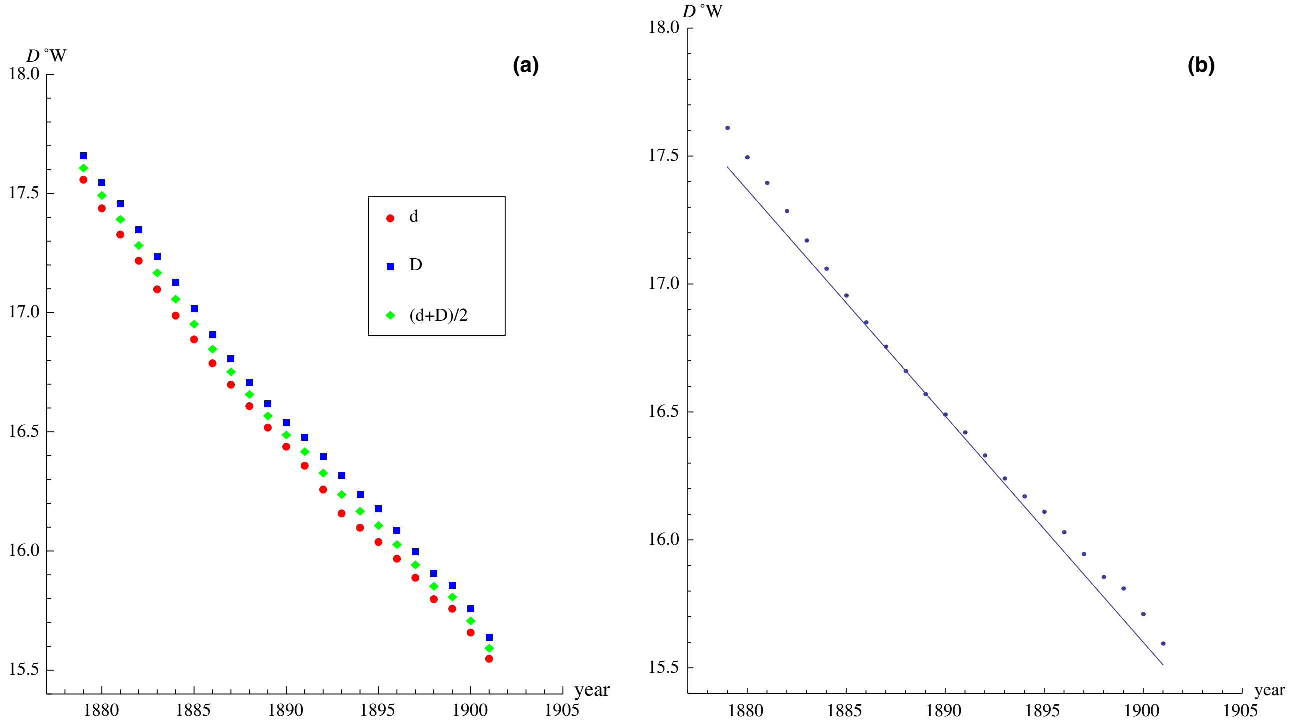

FIGURE 3 (a) Mean declination values for the two measurement times (*d* and *D*), and the average value (*d* + *D*)/2. (b) Mean value least-squares fit

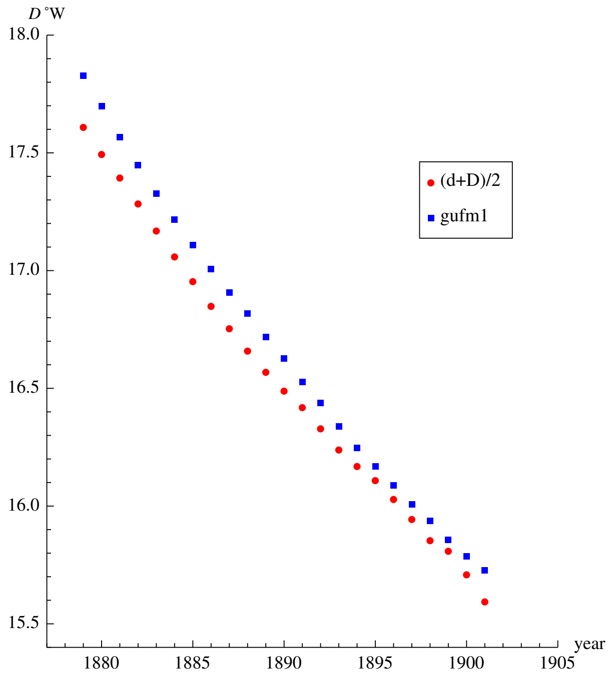

FIGURE 4 Yearly mean value observed (red dots) and calculated with the *gufm1* model (blue dots)

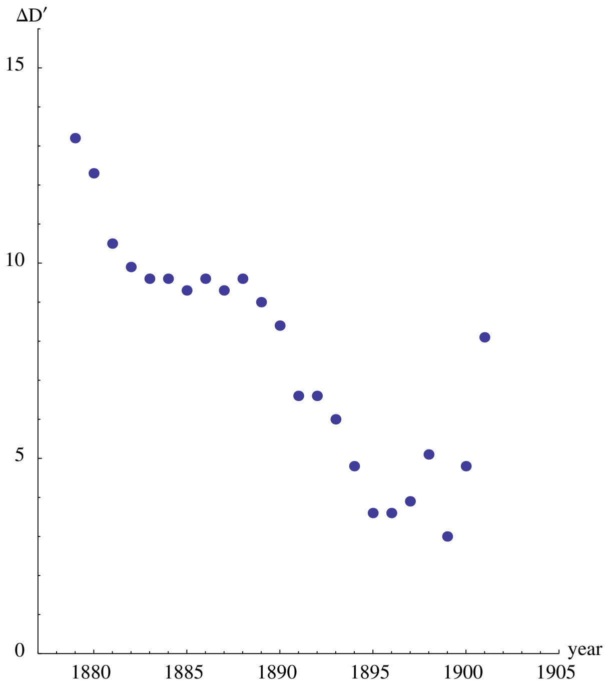

FIGURE 5 Difference between theoretical and observed declination values

in general, but less consistent in the last stage of the measurements, from 1897. This was probably due to the pollution due to electric trams, with the differences between the modelled and the observed values being noisier. Indeed, the observers abandoned their measurement program due to the magnetic noise coming from the city's infrastructure (López Arroyo, 2004; Batlló, 2005).

The recovered data are freely available at the World Data Center PANGAEA at https://doi.org/10.1594/PANGAEA.885886.

OPEN PRACTICES

This article has earned an Open Data badge for making publicly available the digitally-shareable data necessary to reproduce the reported results. The data is available at https://doi.pangaea.de/10.1594/PANGAEA.885886. Learn more about the Open Practices badges from the Center for Open Science: https://osf.io/tvyxz/wiki.

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